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Comparison of Cervical Spine Motion During Application Among 4 Rigid Immobilization Collars

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Objective: To quantify the cervical spine range of motion that occurred during application of 4 rigid cervical immobilization collars, the time of application, and the amount of active range of motion available after application.

Design and Setting: We evaluated the amount of cervical motion that occurred during application of 4 commonly used collars: NECLOC (NL), StifNeck (SN), StifNeck Select (SNS), and Rapid Form Vacuum Immobilizer (VI). Each clinician applied a properly sized collar to both a small- and medium-size model 3 times. After application, active range-of-motion testing was completed with the subject in the supine and seated positions.

Subjects: A total of 17 certified athletic trainers participated.

Measurements: We used 3-dimensional kinematic head and thorax data to calculate peak angular displacement, total linear distance, and total angular distance during application and peak angular displacement during supine and seated range-of-motion testing. Application time was calculated during each trial.

Results: Significant differences between collars were noted for application time, total linear distance, and total angular distance ($P < .01$). The SN and SNS were applied significantly faster and with significantly less total linear distance and total angular distance than the NL and the VI collars. The NL was applied significantly faster and with significantly less total linear distance and total angular distance than the VI. During supine and seated active range-of-motion tests, the SN and SNS permitted significantly less cervical flexion-extension, rotation, and lateral flexion than the NL and VI.

Conclusions: Of the collars tested, the SN and SNS appear to be the optimal collars for use by certified athletic trainers. They were applied with the least motion in the fastest time and provided superior restriction during active range-of-motion testing.

Key Words: extrication collar, cervical collar, cervical range of motion, cervical spine injury, emergency management

A total of 25% of cervical spine injuries occur after the initial injury, termed secondary injury, either during transport or in the early course of treatment.[1] Secondary cervical spine injury may be reduced by proper and rapid stabilization, evaluation, transport, and treatment.[2] Because the relative incidence of cervical spine injuries is low, certified athletic trainers (ATCs) and on-site medical staffs are unlikely to have much real-life experience managing a cervical spine–injured athlete,[3] creating a high-risk situation in which improper handling leading to permanent neurologic damage may be more likely.

Management of the cervical spine–injured athlete begins on the field with proper immobilization of a potentially unstable vertebral column.[3] Effective cervical-collar application and collar integrity are of crucial importance during cervical immobilization. Application of a collar must be accomplished with little to no cervical motion, and once applied, the collar should immobilize the cervical spine. Therefore, the optimal cervical collar must meet a number of criteria.[4] It must be radiographically translucent, be unobtrusive if access to the airway is necessary, not be hampered by varying weather conditions, be disposable or easily sanitized, fit a wide range of neck sizes, effectively restrict motion in the injured portion of the cervical spine, and be easily and rapidly applied without cervical motion at the scene of the injury.[4] Additionally, cervical collars must be adaptable enough to use with various forms of protective equipment.

Previous researchers have used goniometry,[1,4,5] conventional radiography,[6] and fluoroscopy[7] to assess the efficacy of several commercially available cervical collars in preventing motion after application. Most authors have compared a participant's cervical active range of motion (AROM), including flexion-extension, rotation, and lateral flexion before and after cervical-collar application.[1,2,5–7] However, previous researchers, simulating the most common cervical immobilization situation—a car accident—have taken their measurements with a seated participant, in contrast to the typical athletic training injury scenario. Comparison across these studies is difficult because of various measurement techniques, methods, and types of collars.[1]

We found no studies evaluating the amount of motion during application of a rigid cervical collar to a supine model in

a simulated, athletic-related spine-board situation. Therefore, our primary purpose was to determine which of 4 commercially available rigid cervical collars an ATC could apply with the least amount of cervical motion to a supine model. After application, a secondary purpose was to measure the peak cervical AROM allowed by each collar in both the supine and seated positions. The cervical-spine motion considered during both the application and AROM phases of the study included flexion-extension, lateral flexion, and rotation during and after collar application. A tertiary purpose was to measure the amount of time required to apply each cervical collar.

METHODS

Participants

The clinicians in this study were 17 ATCs, 14 of whom were directly affiliated with Georgia Southern University. All clinicians were certified by the National Athletic Trainers' Association Board of Certification and licensed to practice athletic training in the state of Georgia. They had a mean of 5.5 years (range = 1–15 years) of experience in a wide variety of clinical settings. These clinicians were trained at different institutions, 10 of which had accredited athletic training education programs at the time the ATC completed his or her education. The 14 clinicians affiliated with Georgia Southern University were faculty, graduate assistants, or staff ATCs associated with the Graduate Athletic Training Program. The 3 other clinicians were employed by a local hospital and worked in area high schools.

Each cervical collar was applied by the clinicians to 2 male models, one with a small-short neck size and one with a medium-regular neck size. Because of the placement of the motion-capture sensor across the midsternum, male models were used. These 2 models had no prior cervical spine injuries. The models were properly sized before testing for each collar according to the manufacturer's printed instructions.

To maintain stabilization of the model's head while the collar was applied, a head stabilizer was used throughout all trials. Three senior undergraduate athletic training students served as head stabilizers throughout the trials; they were randomly assigned for each session. All clinicians, models, and head stabilizers signed a university institutional review board–approved informed consent form before participating in this study, which was also approved by the board.

Design

A repeated-measures design was used. The 17 clinicians attended 2 data-collection sessions, each lasting approximately 45 minutes: one session with the small-size model and one session with the medium-size model. Model size was counterbalanced among clinicians. During each session, the ATCs performed 3 trials of cervical-collar application with each of the 4 cervical collars. Clinicians were randomly assigned an order in which to apply the collars, a model size, and a head stabilizer during the first session. During the second session, the clinicians applied the collars in a random order with a random head stabilizer to the other model.

Cervical Collars

The cervical collars used in this study represented a variety of the cervical collars currently available. Each was chosen based on its unique characteristics. The NECLOC (NL) cervical collar (Jerome Medical, Moorestown, NJ) (Figure 1) is available in 5 sizes: large, medium, pediatric, small, and stout. It is a 2-piece collar that overlaps and attaches on both sides, with an approximate cost of $16. The StifNeck (SN) cervical collar (Laerdal, Wappingers Falls, NY) (Figure 2) is a 1-piece collar that comes in tall, regular, short, and no neck. It attaches

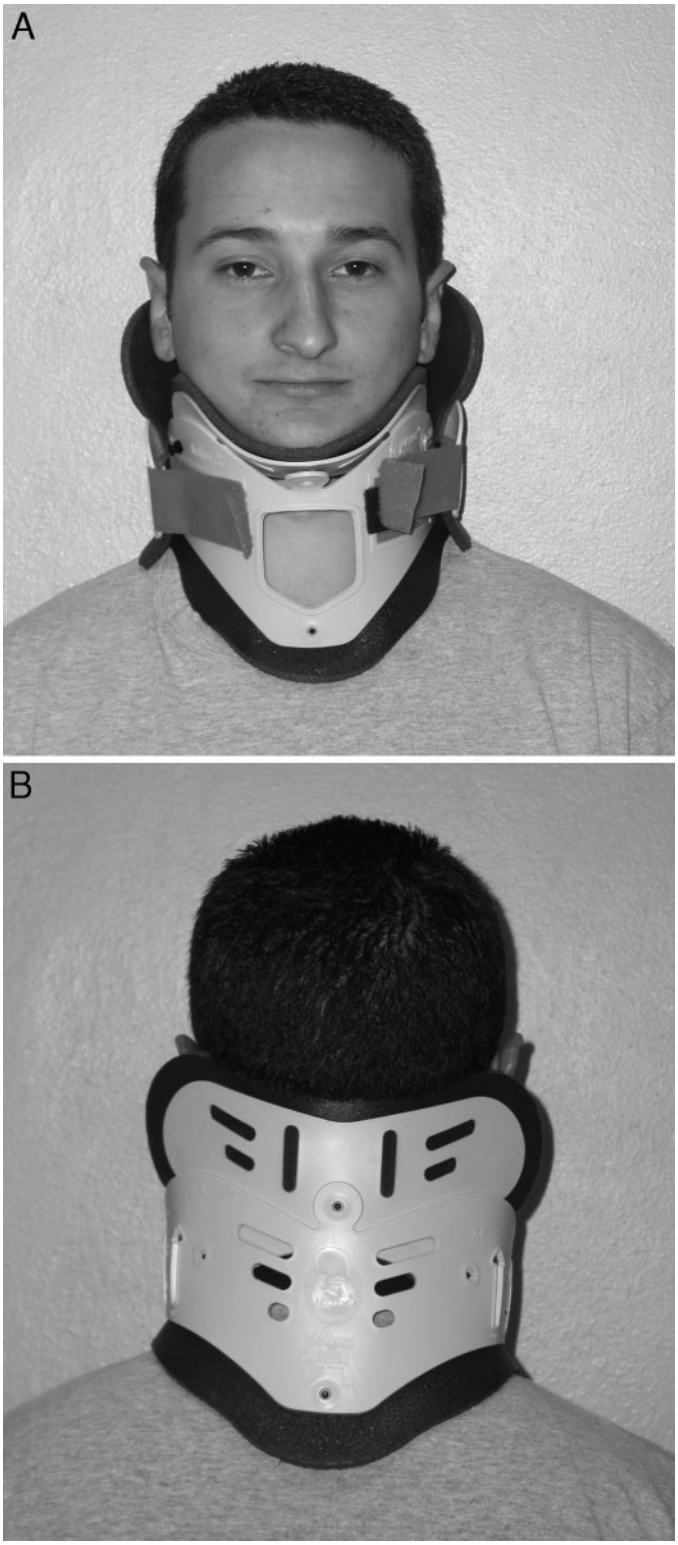


Figure 1. NECLOC Cervical Collar. A, Anterior view. B, Posterior view.

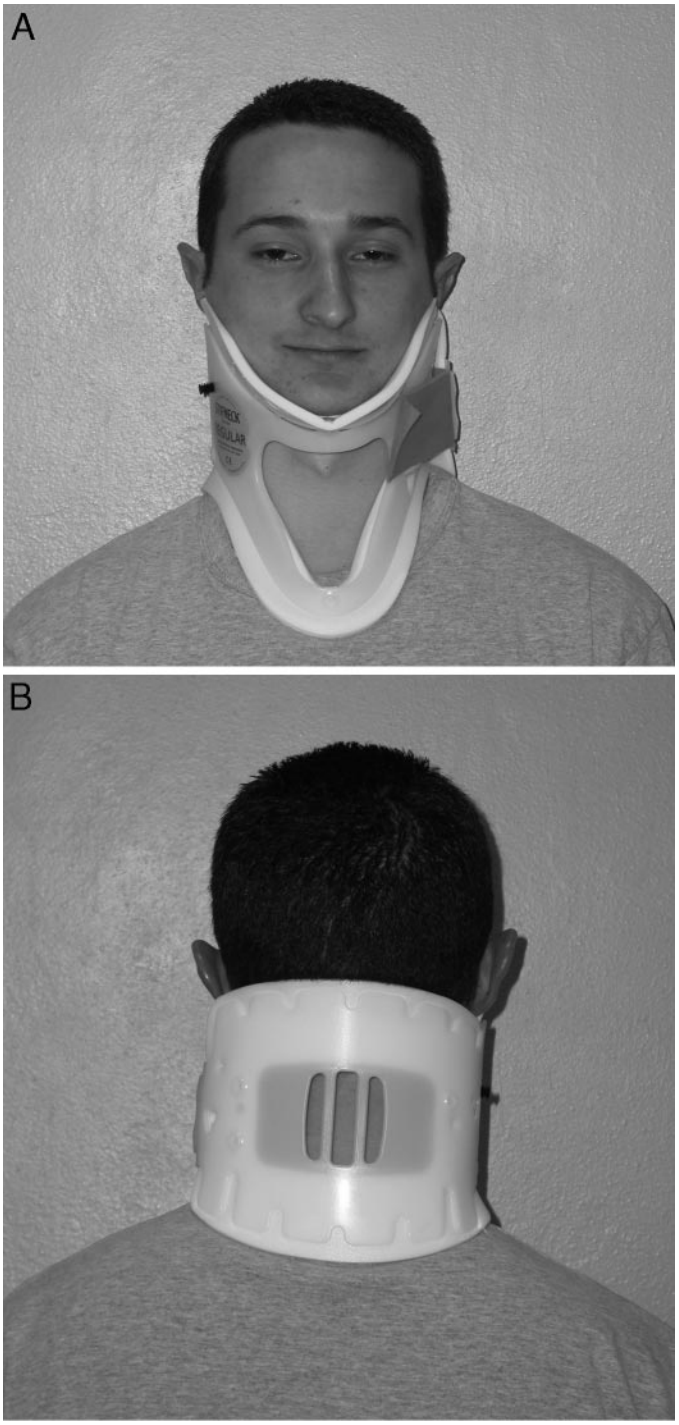


Figure 2. StifNeck Cervical Collar. A, Anterior view. B, Posterior view.

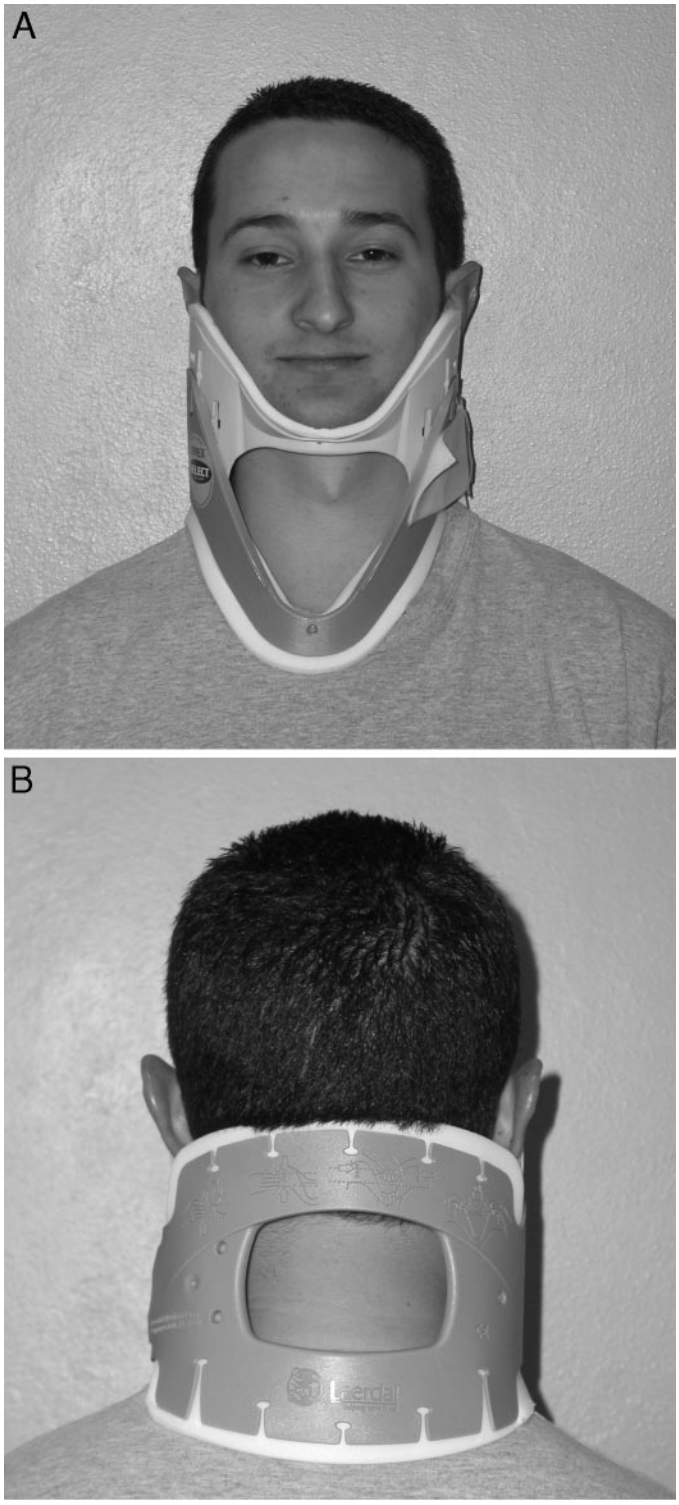
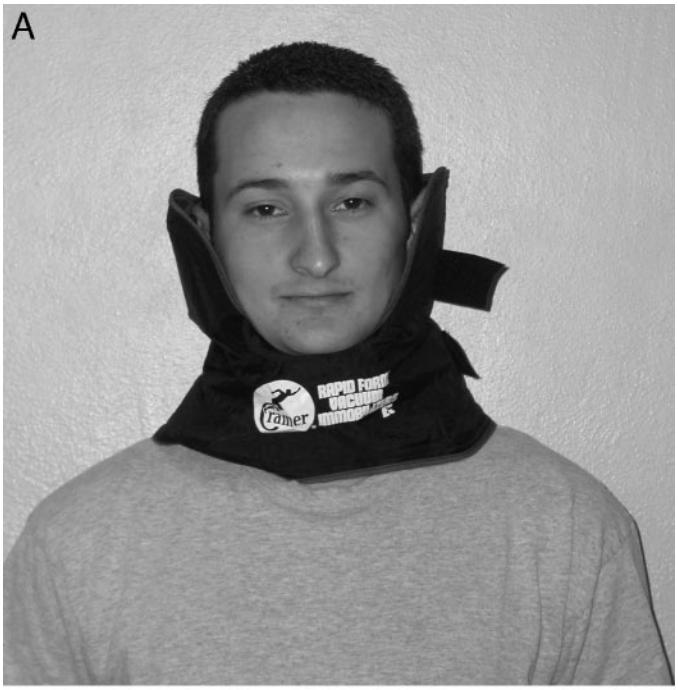


Figure 3. StifNeck Select Cervical Collar. A, Anterior view. B, Posterior view.

on one side with hook-and-loop straps after the rear panel is slid behind the athlete and has an approximate cost of $9. The StifNeck Select (SNS) cervical collar (Laerdal, Wappingers Falls, NY) (Figure 3) is a one-piece collar that can be adjusted to tall, regular, short, and no-neck athletes. It has an approximate cost of $9. After it was sized for the model, the lock tab was pressed to ensure that the collar stayed at the intended size. The SNS attaches on one side with hook-and-loop straps after the rear panel is slid behind the athlete. The Rapid Form Vacuum Immobilizer (VI) cervical collar (Cramer Products, Gardner, KS) (Figure 4) is a nylon bag filled with small beads. Removal of the air within the collar using a hand-held pump forms the tight collar around the athlete's neck. It comes in one size and has the highest cost (approximately $175) in comparison with the other rigid cervical collars used in this study.

Instrumentation

Three-dimensional kinematic data were collected during the application and AROM testing using a 6-degrees-of-freedom,



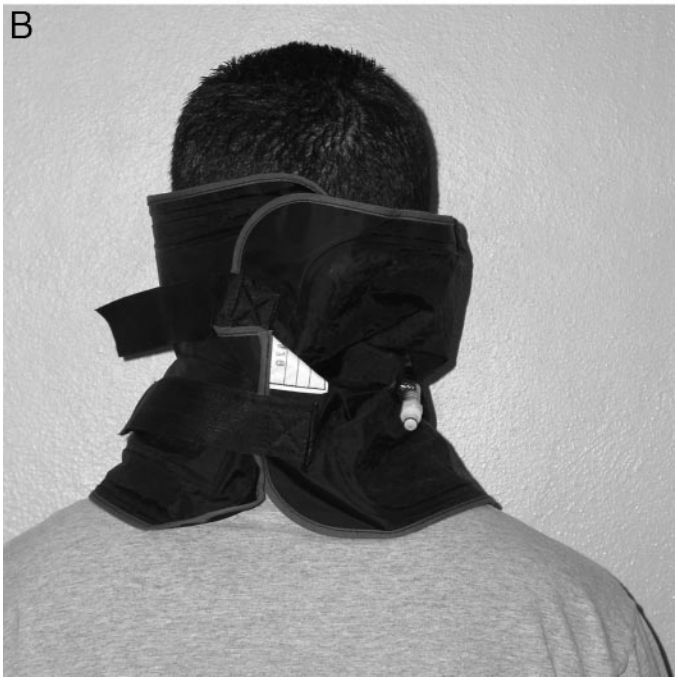


Figure 4. Rapid Form Vacuum Immobilizer Cervical Collar. A, Anterior view. B, Posterior view.

extended-range electromagnetic tracking device (Motion Star, Ascension, Inc, Burlington, VT). The electromagnetic system consisted of multiple receivers that picked up signals from a fixed transmitter. The Motion Monitor Software (Innovative Sports Training, Chicago, IL) was used to collect the sensor data regarding position and orientation relative to a fixed transmitter at 50 Hz. During testing, the models maintained a standard distance from the transmitter. One sensor was secured to the skin overlying the inferiormost point on the sternum, while another sensor was attached to the frontal bone of the cranium. These sites were chosen because they were associated with minimal underlying soft tissue, including muscle and adipose tissue. Calibration was conducted with each model standing in

Figure 5. Application of the NECLOC Cervical Collar.

anatomical position such that the sensor axes were boresighted to the global axes established by the transmitter. In this manner, the positive direction for the local Z-axes pointed to the right, Y-axes superior, and X-axes anterior.

Procedures and Data Collection

Before the actual data-collection session, all clinicians attended a training workshop in order to familiarize themselves with the collars and testing procedures. Before and during the workshop, clinicians were not aware of the study's exact purpose. They were only told that the study would somehow evaluate their performance on cervical-collar application. At the workshop, the clinicians were presented with manufacturer-supplied materials concerning proper collar application. As appropriate, clinicians were required to read the instructions for the collar and watch the video explaining each collar's application. The clinicians practiced applying each collar at least 3 times. The training workshop served to bring application performance with each collar to a plateau and familiarize the clinicians with what would occur during the actual testing session. The models and head stabilizers attended a different workshop, in which each received verbal and written instructions explaining their roles during data collection. The head stabilizers practiced the procedure for head stabilization, while the models practiced the supine and seated cervical AROM test for the actual data collection. In addition, the models' necks were measured for size to determine the appropriate-sized collars based on the manufacturer's instructions.

Clinicians were instructed to perform the cervical-collar application as carefully as possible, keeping in mind that minimizing both cervical motion and application time was of vital importance. The application process was timed to assess differences in applying each collar. While the head stabilizer (with both hands) secured the head in a neutral position, the clinician applied the cervical collar to the model following the manufacturer's instructions (Figure 5). These printed instructions were available for review by the clinician before appli-

Table 1. Application Time and Quantity of Motion Occurring During Application of Each Collar*

Collar	Time (s)†	Total Angular Displacement (°)‡	Peak Angular Displacement (°)	Total Linear Distance (m)§
NECLOC	34.63 ± 9.78	27.40 ± 12.79	4.56 ± 1.79	0.06 ± 0.02
StifNeck	17.09 ± 6.93	17.55 ± 8.90	4.14 ± 1.28	0.03 ± 0.01
StifNeck Select	15.68 ± 5.68	15.52 ± 8.83	3.81 ± 1.38	0.03 ± 0.01
Vacuum Immobilizer	58.09 ± 11.85	43.66 ± 15.75	4.36 ± 1.61	0.10 ± 0.06

*Because there were no significant differences between the models, pooled averages for the 2 models are given.
†StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 7.18, $P < .01$).
‡StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 8.84, $P < .01$).
§StifNeck and StifNeck Select < Vacuum Immobilizer (Tukey Honestly Significant Difference = .06, $P < .01$).

cation, if needed, and were identical to those presented at the training workshop.

During the entire collar application, kinematic data were collected regarding head motion with respect to the thorax. Data collection started once the clinician began to apply the collar to the model and ended once the clinician completed all the application procedures. The principal investigator activated an electronic switch synchronized with the sensor data at the start and the end of the application procedures. Once the collar was applied, the model remained supine and actively moved his head into flexion and extension, right and left rotation, and right and left lateral flexion. The model then moved to a standard wooden chair and sat upright with the shoulders and thoracic and lumbar spine securely placed against the back of the chair. Kinematic data were collected while the model performed the supine and seated AROM. The AROM values were measured to establish the effectiveness of each device in restricting overall cervical AROM.

Data Reduction

Custom software was used for all data-reduction procedures. First, the kinematic sensor data were smoothed at 10 Hz. Using the kinematic data collected during the application and AROM testing (supine and seated), Euler angles (ZY′X″) of the head with respect to the thorax were calculated. Based on the local axes and the above Euler sequence, flexion-extension was first determined as motion occurring around the Z-axis, rotation was next determined as motion occurring around the Y-axis, and lateral flexion was determined last as motion occurring around the X-axis.

For the data collected during collar application, indicated by the electronic switch data, individual angular vectors (flexion-extension, right and left rotation, and right and left lateral flexion) for each collar application were resolved into one composite vector. Using the combined vector, the total angular distance (TAD) and the peak angular displacement (PAD) were calculated. The TAD reflects how much angular motion occurred during the trial, whereas the PAD represents the extreme angular displacement that transpired. In addition, the total linear distance (TLD) of head motion in the 3 dimensions with respect to the thorax was determined and used as a third variable. Finally, the application time was calculated as the length of time between the first switch signal and the end switch signal.

For the supine and seated AROM testing, the PAD during the 3 reciprocal motions (flexion to extension, left to right rotation, and left to right lateral flexion) was determined. These variables represented the quantity of angular motion allowed by a collar during each test (supine and seated).

Statistical Analysis

Separate statistical analyses were conducted for each phase (collar application, supine AROM, and seated AROM). For all analyses, the alpha level was set at .01 to reduce the chance of a type I error. In circumstances when the assumption of sphericity was violated, the Greenhouse-Geisser adjustment was used. When appropriate, Tukey post hoc procedures were used.

Collar Application. The dependent variables for this phase of the investigation, (TAD, PAD, and TLD) during the worst trial were statistically analyzed using separate 2-factor, repeated-measures analyses of variance (model by collar) for each variable. The worst trial, operationally defined as the trial with the largest respective variable magnitude, was determined separately for each variable. The worst trial was used because we were interested in the extreme case. The average time of application across the 3 trials was statistically analyzed using a 2-factor, repeated-measures analysis of variance (model by collar). For each analysis, there were 4 levels of collars (NL, SN, SNS, and VI) and 2 levels of models (small and medium).

Supine and Seated Active Range of Motion. The dependent variable for this phase of the investigation was PAD among the reciprocal 3 motions (flexion-extension, rotation, and lateral flexion). The average of the AROM trials across the 2 models for each of the 17 clinicians was computed. These values were then statistically analyzed with a 1-way analysis of variance for each motion to detect differences in PAD among collars.

RESULTS

Descriptive statistics for collar application and supine and seated AROM testing are presented in Tables 1 through 3, whereas effect sizes for the significant results are presented in Tables 4 through 6.

Collar-Application Time

The SN and SNS application times were significantly less than that for NL, which in turn was significantly less than that for VI ($F_{1.7,27} = 316.56$, $P < .01$). No significant differences were noted between models for collar application time, as evidenced by the model main effect ($F_{1,16} = 0.17$, $P = .68$) and collar-by-model interaction ($F_{1.9,31} = 1.57$, $P = .23$).

Collar Application: Total Angular Distance

Identical significant differences (SNS and SN > NL > VI) as revealed for collar application time ($F_{1.6,25.1} = 96.37$, $P < .001$) were also uncovered for TAD. No significant differences

Table 2. Peak Angular Displacement Occurring During Supine Active Range-of-Motion Testing

Collar	Flexion-Extension (°)*	Left-Right Rotation (°)†	Lateral Flexion (°)‡
NECLOC	38.48 ± 5.30	48.10 ± 6.58	43.61 ± 5.85
StifNeck	33.87 ± 4.14	32.57 ± 6.61	27.86 ± 4.89
StifNeck Select	33.48 ± 4.87	29.13 ± 5.14	27.27 ± 5.28
Vacuum Immobilizer	47.50 ± 5.03	44.16 ± 5.91	35.82 ± 4.57

*StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 3.60, $P < .01$).
†StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 3.72, $P < .01$).
‡StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 2.31, $P < .01$).

Table 3. Peak Angular Displacement Occurring During Seated Active Range-of-Motion Testing

Collar	Flexion-Extension (°)*	Left-Right Rotation (°)†	Lateral Flexion (°)‡
NECLOC	48.44 ± 6.82	48.77 ± 7.90	50.76 ± 6.83
StifNeck	43.02 ± 7.35	36.42 ± 8.61	32.82 ± 6.98
StifNeck Select	40.99 ± 9.12	33.62 ± 7.60	33.22 ± 6.14
Vacuum Immobilizer	65.68 ± 10.33	69.26 ± 6.25	50.06 ± 6.11

*StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 5.35, $P < .01$).
†StifNeck and StifNeck Select < NECLOC < Vacuum Immobilizer (Tukey Honestly Significant Difference = 6.07, $P < .01$).
‡StifNeck and StifNeck Select < NECLOC and Vacuum Immobilizer (Tukey Honestly Significant Difference = 4.30, $P < .01$).

Table 4. Effect Sizes for the Statistically Significant Collar-Application Variables and Comparisons ($P < .01$)

Collar	Time	Total Angular Distance	Total Linear Distance
NECLOC and Vacuum Immobilizer	2.15	1.13	0.89
NECLOC and StifNeck	2.07	0.89	1.89
StifNeck and Vacuum Immobilizer	4.22	2.04	1.63
StifNeck Select and NECLOC	2.37	1.08	1.89
StifNeck Select and Vacuum Immobilizer	4.56	2.20	1.60

Table 5. Effect Sizes for the Statistically Significant Supine Active Range-of-Motion Comparisons ($P < .01$)

Collar	Flexion-Extension	Left-Right Rotation	Lateral Flexion
NECLOC and Vacuum Immobilizer	1.75	*	1.48
NECLOC and StifNeck	0.86	2.35	2.92
StifNeck and Vacuum Immobilizer	2.64	1.85	1.68
StifNeck Select and NECLOC	0.90	3.21	2.93
StifNeck Select and Vacuum Immobilizer	2.83	2.71	1.73

*Comparison not significant.

Table 6. Effect Sizes for the Statistically Significant Seated Active Range-of-Motion Comparisons ($P < .01$)

Collar	Flexion-Extension	Left-Right Rotation	Lateral Flexion
NECLOC and Vacuum Immobilizer	1.997	2.87	*
StifNeck and NECLOC	*	1.49	2.59
StifNeck and Vacuum Immobilizer	2.52	4.37	2.63
StifNeck Select and NECLOC	0.93	1.95	2.70
StifNeck Select and Vacuum Immobilizer	2.53	5.12	2.75

*Comparison not significant.

were seen between models for TAD during collar application, as evidenced by the model main effect ($F_{1,16} = 0.13$, $P = .73$) and collar-by-model interaction ($F_{2.2,35.1} = 1.21$, $P = .32$).

Collar Application: Peak Angular Displacement

No significant differences were demonstrated among collars or between models for PAD during collar application, as evidenced by the interaction ($F_{3,48} = 0.46$, $P = .71$) and main effects for models ($F_{1,16} = 0.001$, $P = .98$) and collars ($F_{3,48} = 2.14$, $P = .11$).

Collar Application: Total Linear Distance

The TLD during collar application for the VI was significantly greater than for NL, SN, and SNS ($F_{1.1,17} = 19.61$, $P < .001$). No significant differences were shown between models for TLD during collar application, as evidenced by the model main effect ($F_{1,16} = 0.11$, $P = .74$) and collar-by-model interaction ($F_{1.1,16.9} = 0.58$, $P = .63$).

Supine Active Range of Motion: Peak Angular Displacement

During the supine AROM testing, the SN and SNS permitted significantly less motion than the NL, which in turn permitted less motion than the VI for flexion-extension ($F_{3,48} = 71.14$, $P < .001$), left and right rotation ($F_{3,48} = 129.36$, $P < .001$), and lateral flexion ($F_{3,48} = 119.69$, $P < .001$).

Seated Active Range of Motion: Peak Angular Displacement

Similar significant differences for the seated ROM were revealed among collars for flexion-extension ($F_{3,48} = 95.29$, $P < .001$) and left and right rotation ($F_{2.2,35.5} = 216.19$, $P < .001$) AROM. The SN and SNS allowed significantly less motion than the NL, which in turn allowed significantly less than the VI. For seated lateral flexion, the SN and SNS permitted significantly less motion than the NL and VI ($F_{3,48} = 118.37$, $P < .001$).

DISCUSSION

In order to prevent secondary spinal injury, clinicians must choose a rigid cervical collar that can be applied with minimal movement and will sufficiently restrict cervical range of mo-

tion during transport. No prior studies were found that quantified cervical spine movement during rigid cervical-collar application. Furthermore, previous authors have only evaluated the efficacy of cervical collars in preventing cervical AROM in a seated model.

Our major purpose was to quantify the amount of cervical movement that occurred during rigid cervical-collar application to a supine model. We hypothesized that the SN and SNS would be applied with significantly less movement than the NL and VI. The rationale behind this hypothesis was based on their 1-piece designs and single-strap attachment. During collar application, significant differences were noted among collars for TLD and TAD. For TAD, the SN and SNS were applied with significantly less movement than the VI, which in turn was applied with less movement than NL. The TLD for SNS, SN, and NL was significantly less than for VI during collar application.

Cervical-collar design characteristics help to explain the significant differences in movement revealed during application. The VI is designed with small beads inside a closed nylon bag; removing air within the bag forms a rigid immobilization collar. The beads add additional thickness, beyond the other collars, that may have caused extraneous movement as the collar was slid behind the model's neck. The 2-piece (NL) had a thicker posterior piece (occipital support) than the SN and SNS, which may have caused additional movement as it was slid behind the neck during application. In addition, the SN and SNS had the thinnest occipital support and visually appeared the easiest to slide behind the model's neck during application. The NL also required 2 straps to be tightened; pulling these 2 straps tighter caused more movement than pulling just 1 strap.

No significant differences were seen among collars with respect to PAD during collar application. This suggests no significant difference in the peak (extreme) movement among collars during application. However, a lack of significant differences does not suggest that the amount recorded is not enough to cause secondary injury but instead implies no differences among our collars. The fundamental need to decrease PAD to a minimum during application cannot be ignored.

It is important to consider the type of movement that occurs as a collar is applied and the type of secondary injury that could be induced. It is difficult to ascertain at what point secondary cervical injury occurs, and therefore, extreme caution must be exercised at all times. Smaller movements that occur often during management (eg, collar application, spine boarding, and transport), quantified as TAD and TLD, may be just as detrimental, if not more so, than one singular instance of peak movement. An important question for future researchers is to determine which variable represents the greatest threat to the integrity of the spinal cord and, thus, the most relevant to identifying an optimal collar.

A tertiary purpose of this study was to measure collar-application time. It is crucial that collar application be completed in a timely manner to facilitate transport of the athlete to a primary care treatment facility. A few seconds can be crucial when the patient is not breathing or lacks a pulse. We hypothesized that the SN and SNS would be applied significantly faster than the other collars. As expected, the SN and SNS were applied in significantly less time than the NL and VI. In addition, the VI took significantly longer to apply than the NL. This result may be attributed to the VI collar design, which requires attachment of a handheld pump and removal of air after application of the collar. The VI also appeared to take longer to place around the cervical spine due to its bulky design. The collars with the fastest overall application, SN and SNS, required only one hook-and-loop strap attachment. Similar to the findings of Rosen et al,[4] VI took significantly longer to apply than NL.

The final purpose of this study was to determine AROM during supine and seated testing. Although these may not seem to be directly related to athletic injury situations, especially the seated AROM testing, AROM has been evaluated as in previous studies.[1,4–6,8] We wanted an assessment that would allow us to compare our results with previous research. The results of the 3 AROM (flexion-extension, rotation, and lateral flexion) trials (for both supine and seated positions) were averaged, as in previous studies.[1,4,5,8–10] In both the supine and seated AROM testing, the VI was hypothesized, due to its larger thoracic area, to restrict significantly more movement than the NL, SN, and SNS. In the supine analyses, significant PAD differences were noted among the collars for flexion-extension, rotation, and lateral flexion. The SN and SNS significantly restricted more motion, whereas the VI was significantly worse for all 3 directions. The NL collar fared better than the VI but worse than the SN and SNS during AROM testing. Because the AROM data were pooled across the 2 models, the large standard deviations associated with the AROM dependent variables are attributable to range-of-motion differences existing between the models.

Similar significant differences between the collars were revealed for the seated AROM testing. Again, the SN and SNS were significantly more restrictive than the VI and NL. In addition, the NL collar provided significantly better flexion-extension and left and right rotation restriction than the VI.

Collar design appeared to play an important role in collar efficacy by preventing supine and seated AROM. A 1-piece design (SN and SNS) seemed to allow for tighter application. The 2-piece (NL) collar appeared more difficult to tighten due to the 2 straps (1 on each side). A 2-strap design appears to be difficult to tighten enough to prevent movement versus the 1-strap attachment collars (SN and SNS). The 2-piece collar (NL) also allowed more lateral flexion and rotation with the overlapping at the sides of the collar, making it difficult to shape the collar securely around the neck. The occipital section was also smaller on the NL than on the SN and SNS, which may have allowed more flexion-extension. A larger posterior design on the NL could limit more AROM and increase the efficacy of the collar. Another aspect of the NL collar that might have hindered its performance was the retaining strap. Watching most data-collection sessions, we noted that most clinicians seemed to pull the strap too tight, in turn making the overlapping hook-and-loop strap difficult to attach and difficult to keep in place.

Although the VI is a 1-piece design, it was less effective when compared with the other collars due to its design. The clinicians were unable to spread the beads equally throughout the collar before application, making the collar asymmetric. The VI also must have all of its air removed for proper application; some clinicians did not remove enough air, leaving the collar too loose for rigid immobilization. The VI was not shaped to fit around the neck securely, and gaps were present where the collar should have fit snugly against the neck

In contrast to our results, previous investigators considered only seated ROM[1,11] and found that 2-piece collars were superior to the 1-piece design. However, this may be due to the

specific types of collars evaluated. Ducker[11] evaluated the NL EMS collar and found it superior to the 1-piece collars. The results of Askins and Eismont[1] were similar to Ducker's[11] findings in that the 2-piece (NL) was the most restricting collar. Our results are also contradictory to a previous study by McGuire et al,[10] whose results illustrated no statistical difference among the NL, SN, and the Philadelphia collar (Philadelphia Cervical Collar Co, Westville, NJ) in stabilizing the cervical spine against a deforming flexion force.[10] However, McGuire et al[10] tested the collars against destabilized cervical spines in cadavers.

The negative results with respect to the VI contrast with those reported by Ransone et al.[6] Possible reasons for this are that the previous authors used a fully padded and helmeted football player. Although the VI can be used with or without shoulder pads and a helmet, it may be more effective and fit more congruently on a padded and helmeted player's cervical spine. One unique benefit of the VI is that it can be used in this manner; none of the other collars can be applied with helmet and shoulder pads in place.

Results from Rosen et al[4] also contradicted our results for the VI. They identified the VI as restricting AROM of the cervical spine more effectively than the NL, Philadelphia, and Philadelphia EM (Philadelphia Cervical Collar Co).[4] This may be due to the type of the VI evaluated; the previous authors used a different brand of rigid vacuum immobilizer.

Although not one of our primary purposes, we were concerned with any differences that occurred between models during collar application. No significant differences were demonstrated between the models during collar application. This was expected because both models were instructed to lie passively supine in the testing area. We believe properly sized collars can be applied to a small- or medium-size model with equal effectiveness.

Many possibilities exist for future research in the area of rigid cervical collars. Because we measured cervical spine motion indirectly, as head movement with respect to the thorax, the cervical level(s) at which movement was occurring could not be determined. In addition, as with most motion-analysis techniques used in athletic training research, how well the sensor-markers applied to the skin accurately reflect underlying movement of the bones is always a question. We chose anatomical sites associated with little skin movement for the electromagnetic sensors, but the potential for disparity exists. Thus, more detailed analysis is necessary to determine the exact location of the movement in the cervical spine, as well as how well the sensor-markers accurately reflect underlying movement of the head and neck. Future researchers should also consider the direction and amount of movement that occurs with collar application. Furthermore, as Ray et al[12] reported, future research is recommended to consider if the application movements we documented significantly exceed the movements attributable to breathing. It is also important to note we evaluated AROM, which is somewhat subjective and possibly irregular in terms of the force applied by the model to the collar. A few investigators have equalized the force applied by the subject to the collar; equalizing this force may be necessary to standardize results between studies. Last, the use of collars with halo and thoracic extensions needs to be researched and possibly considered for use in athletic situations. These types of collar additions are widely accepted as more restrictive than rigid cervical collars alone.

Our results are clinically significant because in dealing with the uncertainty of spinal-cord injury, it is always essential to err on the side of caution and choose a collar that can be applied with little to no movement and that provides the most restriction during AROM. Our findings support the use of 1-piece collars with 1-strap attachments (SN and SNS). The 1-piece design was applied with less movement and restricted more cervical movement during AROM testing. The ideal collar, we suggest, would be applied rapidly with no cervical movement and adequately prevent cervical motion once applied. From these results, among the collars tested, we determined that the SN and SNS are the optimal collars for use by ATCs.

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